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RESEARCH MEMORANDUM

COMPARISON OF PERFORMANCE OF AN-F-58 FUEL AND GASOLINE IN J34-WE-22 TURBOJET ENGINE

By Harry W. Dowman and George G. Younger

Lewis Flight Propulsion Laboratory
Cleveland, Ohio

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS
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COMPARISON OF PERFORMANCE OF AN-F-58 FUEL AND GASOLINE IN J34-WE-22 TURBOJET ENGINE

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SUMMARY

As part of an investigation of the performance of AN-F-58 fuel in various types of turbojet engine, the performance of this fuel in a 3000-pound-thrust turbojet engine has been investigated in an altitude test chamber together with the comparative performance of 62-octane gasoline.

The investigation of normal engine performance, which covered a range of engine speeds at altitudes from 5000 to 50,000 feet and flight Mach numbers up to 1.00, showed that both the net thrust and average turbine-outlet temperatures were approximately the same for both fuels. The specific fuel consumption and the combustion efficiency at the maximum engine speeds investigated were approximately the same for both fuels at altitudes up to 35,000 feet, but at an altitude of 50,000 feet the specific fuel consumption was about 9 percent higher and the combustion efficiency was correspondingly lower with the AN-F-58 fuel than with gasoline. The low-engine-speed blow-out limits were about the same for both fuels. Ignition of AN-F-58 fuel with the standard spark plug was possible only with the spark plug in a clean condition; ignition was impossible at all flight conditions investigated when the plug was fouled by an accumulation of liquid fuel from a preceding false start. Use of an extended-electrode spark plug provided satisfactory ignition over a slightly smaller range of altitudes and flight Mach numbers than for gasoline with the standard spark plug.

Radial temperature gradients at the turbine outlet were about the same for both fuels at an altitude of 20,000 feet. At an altitude of 50,000 feet, the difference in average temperature between the blade tip and the root was about 240° F greater for AN-F-58 fuel than for gasoline and the spread between the maximum and minimum temperatures at a given radial location was from 150° to 300° F less for AN-F-58 fuel than for gasoline. After 30 hours and 11 minutes of operation with AN-F-58 fuel, 240 grams of hard carbon deposits were built up on the combustor basket near the fuel nozzles.

INTRODUCTION

The need of the armed forces for a fuel for turbojet engines that would be available in greater quantities than those now in use has led to the consideration of a new fuel specification, AN-F-58, which has much wider limits than the specifications of current turbojet fuels. An extensive program to determine the suitability of fuel conforming to the AN-F-58 specification is being conducted at the NACA Lewis laboratory on several types of turbojet engine and combustor.

As part of this general program, the performance of AN-F-58 fuel was investigated during August and September 1948 in a 3000-pound-thrust turbojet engine in an altitude test chamber and the results are reported. This investigation included, for comparison, the performance of the engine with 62-octane gasoline. The normal performance of the engine was investigated over a range of engine speeds at altitudes from 5000 to 50,000 feet and for flight Mach numbers from 0.22 to 1.00. The low-engine-speed blow-out limits, the altitude starting limits, and the turbine-outlet gas-temperature gradients for both fuels were determined at several simulated flight conditions. The use of AN-F-58 fuel for cold-weather starts at zero-ram, sea-level conditions and the amount of carbon deposited in the combustor with this fuel were also investigated.

FUELS

Two types of fuel conforming to the AN-F-58 specification were used in the investigation. These two fuels are designated NACA numbers 48-206 and 48-210 and the analysis of each, with the AN-F-58 specifications, is given in table I. The gasoline that was used for comparative performance data was a clear, 62-octane gasoline and its analysis is also included in table I.

APPARATUS AND INSTRUMENTATION

The investigations were conducted with a modified experimental model of the J34 engine and a J34-WE-22 engine (hereinafter designated engine A and engine B, respectively) having a rated speed of 12,500 rpm and a thrust rating of 3000 pounds at zero-ram, sea-level conditions. The main components of the engines include an 11-stage axial-flow compressor, a double-annulus combustor, and a two-stage turbine. The two engines were similar in general design and differed only in minor details; both engines incorporated the manufacturer's recent modifications to the combustor basket and the eleventh-stage compressor blading. The combustor basket has 3/32-inch anticoking holes on both the inner and outer rings.

Because of frequent failures of the pump and the governor assembly in the fuel system, this assembly was replaced by a standard J33 fuel pump, throttle, and barometric control.

In the interest of expediency, an existing setup, which incorporated an afterburner, was used for all performance runs conducted with engine A. The afterburner was inoperative for all investigations reported herein and functioned merely as an engine tail pipe. The adjustable nozzle of this afterburner was fixed in a position that provided approximately limiting turbine-inlet gas temperature at maximum rated speed, zero-ram, sea-level conditions and was held locked in this position throughout the investigation. Engine B, which replaced engine A after a turbine failure, was equipped with a nonafterburning tail pipe and an NACA adjustable-area nozzle. The adjustable-area nozzle of this engine was also locked in position to provide approximately limiting turbine-inlet gas temperature at zero-ram, sea-level conditions.

The general arrangement of the engine setup in the altitude test chamber is shown in figures 1 and 2. The test chamber is 10 feet in diameter and 57 feet long and includes air-inlet and exhaust-outlet piping, an inlet-air honeycomb, blow-out patches, cooling-air duct, and necessary instrumentation bulkheads. The engine is mounted on a thrust stand and is flexibly connected to a forward baffle (fig. 2), which confines the air flow to the engine inlet and provides a means of maintaining a pressure difference across the engine. A rear baffle is installed around the engine tail pipe to serve as a heat barrier and to prevent recirculation of exhaust gases around the engine. The engine thrust is balanced and measured through a lever arrangement by a null-type air-pressure diaphragm. The forces introduced into the thrust-measuring system by the pressure differences across the two baffles were determined by calibration.

For the investigation of the ignition characteristics of the engine, three different spark plugs, which are shown in figure 3, were used. The spark plug shown in figure 3(a) is a standard spark plug for the J34 engine and that shown in figure 3(b) is a standard plug that was modified by milling longitudinal slots in the outer electrode shell to allow fuel drainage. The spark plug shown in figure 3(c) is an extended-electrode type, which was fabricated at this laboratory. The spark gap for this spark plug was from 0.090 to 0.100 inch. The standard engine ignition system, which incorporates two high-tension coils, was used with all three spark plugs.

Air flow, fuel flow, engine speed, and temperature and pressure measurements at various stations in the engine and test

chamber were measured with standard instrumentation. The instrumentation for the measurement of turbine-outlet gas temperatures consisted of three rakes of nine unshielded, chromel-alumel thermocouples each installed about $2\frac{1}{2}$ inches downstream of the turbine 1070
outlet.

The turbine-inlet gas-temperature limits of the engine were obtained from readings of thermocouples installed at the turbine outlet by the engine manufacturer. The thermocouples were calibrated in conformance with the engine manufacturer's specifications.

The values of combustion efficiency presented are defined as the ratio of the actual enthalpy rise of the gases in passing through the engine divided by the theoretical enthalpy rise, when complete combustion of the fuel is assumed. The enthalpy of the inlet-air and the exhaust gases were determined from the measured compressor-inlet temperature and the turbine-outlet gas temperature with the aid of thermodynamic charts.

DATA CORRECTIONS

All data were corrected by the following factors:

$$\delta = \frac{\text{static pressure at engine discharge, (lb/sq in.)}}{14.7}$$

$$\theta = \frac{\text{static temperature at engine inlet, } (^{\circ}\text{R})}{519}$$

The corrected performance parameters are:

F_n/δ corrected net thrust, (lb)

$f_n/\sqrt{\theta}$ corrected specific fuel consumption based on net thrust, ((lb/hr)/lb net thrust)

$N/\sqrt{\theta}$ corrected engine speed, (rpm)

T_5/θ corrected tail-pipe gas temperature, ($^{\circ}$R)

$W_f/\delta\sqrt{\theta}$ corrected fuel flow, (lb/sec)

PROCEDURE AND RESULTS

Altitude Performance with AN-F-58 Fuel

The altitude performance of engine A using AN-F-58 fuel (NACA fuel numbers 48-206 and 48-210) was investigated and found satisfactory over a range of altitudes from 5000 to 50,000 feet at flight Mach numbers from 0.25 to 0.85. Engine-inlet pressures and temperatures were maintained at values corresponding to NACA standard air at simulated flight conditions and standard NACA altitude pressure was maintained at the engine outlet. The recorded and corrected values of engine net thrust, specific fuel consumption, tail-pipe gas temperature, and fuel flow for the range of engine speeds and flight conditions investigated, as well as the fuel used, are presented in table II. Although an engine failure during the investigation prevented the determination of comparative performance data on the same engine with gasoline, these data illustrate the range of conditions over which the engine satisfactorily operated with AN-F-58 fuel. At altitudes of 45,000 and 50,000 feet, the maximum operable engine speed was limited to the values indicated in table II by excessive tail-pipe gas temperatures, which were believed to be partly caused by burning of fuel through the turbine.

Engine starts during this investigation of altitude performance of the engine were unusually hot and accompanied by longer time intervals between the introduction of the fuel and the start of combustion than usually experienced with gasoline. This difficulty was believed to be caused by operational technique rather than the characteristics of the fuel and was not again encountered in the investigation.

Comparison of Altitude Performance

with AN-F-58 Fuel and Gasoline

The performance with AN-F-58 fuel and with gasoline, for comparative purposes, was determined in engine B. This investigation was conducted with AN-F-58 fuel (NACA fuel number 48-210) for a range of engine speeds from 9000 to 12,500 rpm and at the various simulated flight conditions listed in the following table:

Altitude (ft.)	Flight Mach number
5,000	0
20,000	.60, .85, 1.00
35,000	1.00
50,000	.85

1070

Comparisons of the corrected values of net thrust, tail-pipe gas temperature, specific fuel consumption based on net thrust, and combustion efficiency for the two fuels are presented at the various flight conditions in figures 4, 5, 6, and 7, respectively. At all flight conditions investigated, the corrected net thrust and corrected tail-pipe gas temperature were approximately the same for the two fuels, as shown in figures 4 and 5, respectively.

The specific-fuel-consumption curves presented in figure 6 were obtained from the faired curves of corrected net thrust and corrected fuel flow for each flight condition. The data are presented in this manner to eliminate the effect of scatter on the specific-fuel-consumption curves. At an altitude of 5000 feet, the corrected specific fuel consumption is approximately the same for both fuels (fig. 6(a)). For an altitude of 20,000 feet and a flight Mach number of 0.60, the specific fuel consumption based on net thrust is slightly greater for AN-F-58 fuel than for gasoline over the range of engine speeds investigated (fig. 6(b)). At flight Mach numbers of 0.85 and 1.00 and an altitude of 20,000 feet, the specific fuel consumption for the two fuels is approximately the same at all engine speeds (figs. 6(c) and 6(d)). The heating value of AN-F-58 fuel is approximately 1 percent lower than that of gasoline (table I) and thus introduces a corresponding difference in the specific fuel consumption.

The corrected specific fuel consumption at an altitude of 35,000 feet and a flight Mach number of 1.00 is shown to be slightly higher for AN-F-58 fuel than for gasoline at all engine speeds (fig. 6(e)). At an altitude of 50,000 feet and a flight Mach number of 0.85, the corrected specific fuel consumption with AN-F-58 fuel is considerably greater than with gasoline at the low engine speeds and slightly greater at high engine speeds, as shown in figure 6(f). At this same altitude for the maximum operable engine speed, the specific fuel consumption for AN-F-58 fuel was about 9 percent higher than for gasoline.

The combustion efficiency, which is presented in figure 7, is approximately the same for both fuels at an altitude of 5000 feet (fig. 7(a)). At an altitude of 20,000 feet, the combustion efficiency is slightly lower for AN-F-58 fuel than for gasoline at flight Mach numbers of 0.60 and 0.85 (figs. 7(b) and 7(c), respectively) and slightly higher at a flight Mach number of 1.00 (fig. 7(d)) over the entire range of engine speeds investigated. Although the trend of the combustion-efficiency curves for the two fuels with flight Mach number is similar to the trend of the specific-fuel-consumption curves, some differences exist in the percentage of change in the performance with the two fuels and in the changes with engine speed. The combustion efficiency at an altitude of 35,000 feet and a Mach number of 1.00 (fig. 7(e)) is slightly higher for gasoline than for AN-F-58 over the entire range of engine speeds, although the difference is small at the maximum and minimum engine speeds. The combustion efficiency at an altitude of 50,000 feet and a flight Mach number of 0.85 (fig. 7(f)) is considerably lower with AN-F-58 fuel than for gasoline over the entire range of engine speeds investigated. The difference in combustion efficiency at maximum engine speed for the two fuels is about the same as the differences in specific fuel consumption previously noted.

Low-Engine-Speed Blow-Out with AN-F-58 Fuel and Gasoline

The conditions at which combustion blow-out occurred were determined by gradually reducing the engine speed while holding the altitude and flight Mach number conditions constant. While the engine speed was being reduced, attempts were occasionally made to accelerate the engine in order to assure that dead-band operation was not being encountered. The occurrence of combustor blow-out was noted by a rapid reduction in engine speed and tail-pipe gas temperature. These blow-out experiments were conducted with AN-F-58 fuel (NACA fuel number 48-210) in engine A and, for comparison, with gasoline in engine B. The two different engines used for this investigation might result in different normal performance for the two fuels but no significant difference is expected in the altitude blow-out limits because both engines were of the same basic design.

The altitude blow-out limits of both fuels are presented in figure 8 in which the altitude is plotted against the engine speed at which blow-out occurred for flight Mach numbers of 0.25 and 0.60. The altitude blow-out limits of the two fuels are the same at a flight Mach number of 0.60. For a flight Mach number of 0.25 at altitudes above 42,500 feet, a lower engine speed could be attained before blow-out occurred with AN-F-58 fuel than with gasoline. For the altitudes investigated below 42,500 feet, the opposite results were obtained. The differences in the altitude limits are generally within the normal reproducibility of this type of data; from the limited range of these data, no significant differences in altitude limits for the two fuels could therefore be established.

Altitude Starting Characteristics

The altitude starting characteristics of AN-F-58 fuel were investigated with NACA fuel 48-210 in engine A and, for comparison, with gasoline in engine B. The procedure used to start the engine consisted in obtaining the windmilling speed of the engine at the particular flight conditions, turning on the ignition, and advancing the fuel throttle. The ignition and the fuel flow were maintained for a period of 30 seconds before the attempted start was considered unsatisfactory. At each flight condition investigated, a series of three attempts was made before starts at the particular condition were considered impossible. If ignition of the fuel was obtained at windmilling speed, an attempt was also made to accelerate the engine. Immediately after ignition, the pressure in the exhaust end of the test chamber increased from 4 to 10 inches of mercury and this pressure surge prevented these experiments from being a true simulation of flight conditions. The altitude pressure was restored to its correct value in about 10 seconds and the engine was accelerated after the correct conditions had become stabilized.

The first spark plug used in the starting experiments was the standard spark plug (fig. 3(a)). The experimental results with this spark plug are shown in figure 9(a), which includes data for satisfactory starts, burner ignition without engine acceleration, and no ignition. The spark plug was cleaned for each experiment. If an attempted start was unsuccessful, the spark plug filled with fuel, which prevented satisfactory ignition at any operating condition. Although starts were obtained at altitudes up to 30,000 feet at low flight Mach numbers (fig. 9(a)), practically the use of the standard spark plug would not provide satisfactory engine starting at any flight condition.

The second spark plug used was the modified spark plug (fig. 3(b)). Several attempts to start the engine with this spark plug at an altitude of 8000 feet and a flight Mach number of 0.30 were unsuccessful and further use of this spark plug was therefore discontinued.

The third spark plug used was the extended-electrode type (fig. 3(c)). Results of starting experiments with this spark plug are presented in figure 9(b). For all these experiments, the spark plug was used without cleaning between runs. During the experiment in the region of unsatisfactory starts, occasional starts were made at satisfactory starting conditions to assure that the ignition system was functioning properly. These data are insufficient to establish definitely the boundaries of the ignition limits and the areas in figure 9(b) that separate the regions of successful and unsuccessful attempts are drawn primarily for ease of interpreting the data. At 30,000 feet, successful starts could be made only at a flight Mach number of 0.40, whereas at altitudes from sea level to 10,000 feet starts were successful at flight Mach numbers from 0 to 0.50. The results of the starting characteristics of gasoline, which were investigated with the standard spark plug, are presented in figure 9(c) in a similar manner to that used in figure 9(b) for AN-F-58 fuel. The dashed lines for starting limits of the AN-F-58 fuel from figure 9(b) are also included for comparison. For flight Mach numbers below 0.50, the altitude starting limit for gasoline was approximately 10,000 feet higher than for AN-F-58 fuel; satisfactory starts were also obtained over a wider range of flight Mach numbers at low altitudes for gasoline than for AN-F-58 fuel. Even with the extended-electrode spark plug, the starting characteristics of AN-F-58 fuel were slightly poorer than those of gasoline with the standard spark plug and further development of the spark-plug design is therefore required to obtain ignition of AN-F-58 fuel comparable to that of gasoline in this engine.

Cold-Weather, Sea-Level Starting Characteristics with AN-F-58 Fuel

Cold-weather starting experiments were simulated at zero-ram, sea-level conditions with AN-F-58 fuel 48-210 in engine A at inlet-air temperatures of -30° and -50° F. Comparative experiments with gasoline were not conducted. For these starting experiments, the engine was run from zero speed with the standard cranking motor after it had been previously windmilled for a sufficient period of time to bring the temperatures throughout the engine into equilibrium. Both the fuel and the lubricating oil were supplied to the engine from outside tanks at a temperature of about 70° F and therefore only the fuel and the oil contained in the engine parts were at the reduced temperature of the experiment. At the conditions of -30° and -50° F, the engine was successfully started and accelerated on the first attempt. At -50° F, however, a delay of nearly 30 seconds occurred before the fuel ignited and the resulting start was very hot.

Comparison of Turbine-Outlet-Gas-Temperature Distribution

with AN-F-58 Fuel and Gasoline

The radial temperature distribution at the turbine outlet with both AN-F-58 fuel and gasoline are shown in figures 10(a) and 10(b) for a flight Mach number of 0.85 and altitudes of 20,000 and 50,000 feet, respectively. These data were obtained at an engine speed of approximately 12,025 rpm at an altitude of 20,000 feet and at approximately 12,050 rpm at an altitude of 50,000 feet. Curves are shown for maximum, average, and minimum temperatures with the maximum and minimum temperatures being the highest and lowest temperatures, respectively, at each radial thermocouple location and are not necessarily at the same circumferential position. For both altitudes, the average turbine-outlet temperatures for the two fuels are about the same, as previously indicated in figure 5. At an altitude of 20,000 feet, there is very little difference in the temperature distribution for the two fuels. At 50,000 feet, the highest maximum temperature, which occurred near the blade roots, was about the same for both fuels (fig. 10(b)). The difference in average temperature between the blade tip and the root, however, was about 240° F greater for AN-F-58 fuel than for gasoline and the spread between the maximum and minimum temperatures is about 300° F less at the blade roots and about 150° F less at the blade tips for the AN-F-58 fuel than for gasoline.

Carbon Deposition

The completion of the program with AN-F-58 fuel in engine A required about 30 hours and 11 minutes of engine operation after which time the engine was disassembled for inspection. Hard carbon deposits were built up on the inside of both the inner and outer annuli of the combustor basket near the fuel nozzles to a height of about 1/2 inch. A photograph of these carbon deposits is shown in figure 11. The total weight of the carbon deposits was 240 grams. No serious warpage or other deterioration of the combustor basket was observed. Because engine B was operated on both AN-F-58 fuel and gasoline without disassembly for inspection, no evaluation of carbon deposits formed by gasoline was made; carbon deposits formed by gasoline during other investigations, however, have been very small or completely absent.

The exhaust jet from the engine when using AN-F-58 fuel, which was observed at sea-level conditions, was characterized by a faint haze very similar to that which usually occurs with gasoline. Much heavier carbon deposits were, however, built up on

the walls of both the test chamber and the tail pipe with the AN-F-58 fuel than were encountered with gasoline. A considerable amount of liquid fuel was also present on the surfaces of the tank and in puddles on the bottom of the test chamber after an
1070 engine shutdown following altitude operation with AN-F-58 fuel. Similar phenomena were not usually observed with gasoline.

SUMMARY OF RESULTS

The following results were obtained in a comparison of the altitude performance of AN-F-58 fuel and gasoline in a 3000-pound-thrust turbojet engine:

1. Satisfactory operation of the engine was obtained with AN-F-58 fuel over a range of engine speeds for altitudes from 5000 to 50,000 feet and for flight Mach numbers from 0.25 to 1.00. At altitudes of 45,000 and 50,000 feet, the maximum operable engine speed was limited to values less than the rated speed by excessive tail-pipe gas temperatures.

2. The net thrust and average tail-pipe gas temperatures were approximately the same for both fuels for altitudes from 5000 to 50,000 feet and flight Mach numbers from 0.60 to 1.00. The specific fuel consumption and combustion efficiency at the maximum engine speeds investigated were approximately the same for both fuels at altitudes up to 35,000 feet, but at an altitude of 50,000 feet the specific fuel consumption was about 9 percent higher and the combustion efficiency correspondingly lower with the AN-F-58 fuel than with gasoline.

3. The low-engine-speed blow-out limits for the two fuels at a flight Mach number of 0.60 were about the same and differed only slightly at a flight Mach number of 0.25.

4. Ignition of AN-F-58 fuel with the standard spark plug was possible only with the spark plug in a clean condition; ignition was impossible at all flight conditions investigated when the plug was fouled by an accumulation of liquid fuel from a preceding false start. The use of an extended-electrode spark plug with AN-F-58 fuel provided satisfactory ignition over a slightly smaller range of altitudes and flight Mach numbers than for gasoline with the standard spark plug. Zero-ram, sea-level starts with AN-F-58 fuel were successful at inlet-air temperatures as low as -50° F.

5. The radial temperature gradients at the turbine outlet were about the same with both fuels at an altitude of 20,000 feet; at an altitude of 50,000 feet, the difference in the average

temperature between the blade tip and the root was about 240° F greater for AN-F-58 fuel than for gasoline and the spread between the maximum and minimum temperatures at a given radial location was from 150° to 300° F less for AN-F-58 fuel than for gasoline, the difference being greatest at the blade-root section.

6. During the investigation with AN-F-58 fuel, which involved an operating time of 30 hours and 11 minutes, about 240 grams of hard carbon were found to have been deposited on the combustor basket near the fuel nozzles.

Lewis Flight Propulsion Laboratory,
National Advisory Committee for Aeronautics,
Cleveland, Ohio.

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1070

TABLE I - DESCRIPTION OF FUELS USED

	AN-F-58 specification	Analysis		
		AN-F-58		Gasoline
		NACA fuel number		
		48-206	48-210	
A.S.T.M. distillation D 86-46, °F				
Initial boiling point	-------------	100	102	106
Percentage evaporated				
5	-------------	125	150	124
10	-------------	145	174	141
20	-------------	195	234	160
30	-------------	306	286	176
40	-------------	355	322	190
50	-------------	380	360	203
60	-------------	406	390	211
70	-------------	430	412	221
80	-------------	459	444	231
90	425(min.)	501	480	250
Final boiling point	600(max.)	568	546	340
Residue, (percent)	1.5(max.)	1.0	0.8	-------
Loss, (percent)	1.5(max.)	0.2	0.2	-------
Freezing point, °F	-76(max.)	< -76	< -76	-------
Aromatics, (percent by volume)				
A.S.T.M. D-875-46T	30(max.)	23	23	-------
Silica gel[a]	-------------	23	29	-------
Viscosity, (centistokes at -40° F)	10.0(max.)	3.93	4.26	-------
(centistokes at 100° F)	-------------	0.93	0.89	-------
Bromine number	14.0(max.)	4.0	------	-------
Reid vapor pressure (lb/sq in.)	5-7(max.)	5.1	5.7	-------
Hydrogen-carbon ratio	-------------	0.161	0.153	0.183
Heat of combustion (Btu/lb)	18,200(min.)	18,630	18,480	18,635
Specific gravity	-------------	0.786	0.794	0.706

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[a]Reference 1.

[redacted]

TABLE II - PERFORMANCE OF 3000-POUND-THRUST TURBOJET ENGINE WITH AN-F-58 FUEL

Altitude (ft)	Flight Mach number,	Engine speed (rpm)		Net thrust (lb)		Specific fuel consumption based on net thrust, ((lb/hr)/lb thrust)		Tail-pipe temperature, (°R)		Fuel flow (lb/sec)		NACA fuel number
		Read	Corrected	Read	Corrected	Read	Corrected	Read	Corrected	Read	Corrected	
5,150	0.2551	10,480	10,736	1343	1624	1.296	1.328	1312	1377	0.484	0.599	48-210
5,200	.2551	11,532	11,778	1861	2245	1.177	1.202	1410	1471	.608	.750	48-210
5,200	.2551	12,000	12,244	2076	2505	1.141	1.164	1444	1503	.658	.810	48-210
5,200	.2551	12,548	12,791	2259	2725	1.185	1.208	1529	1589	.744	.915	48-210
5,100	.6047	10,520	10,740	1065	1285	1.477	1.508	1183	1233	.437	.538	48-210
5,100[a]	.6047	11,540	11,758	1542	1860	1.401	1.427	1301	1350	.600	.738	48-210
19,950	.6072	10,536	11,366	717	1578	1.370	1.477	1172	1363	.273	.648	48-206
19,900	.6056	11,448	12,378	1012	2210	1.316	1.423	1295	1514	.370	.874	48-206
19,950	.6072	11,920	12,902	1157	2546	1.356	1.468	1362	1596	.436	1.038	48-206
19,950	.6063	12,440	13,450	1308	2878	1.339	1.447	1460	1707	.486	1.157	48-206
19,950	.2462	10,500	11,264	901	1976	1.264	1.356	1266	1457	.316	.744	48-206
19,950	.2462	11,468	12,330	1165	2555	1.185	1.275	1378	1593	.384	.905	48-206
19,900	.2462	11,968	12,867	1267	2759	1.199	1.289	1467	1696	.422	.988	48-206
19,950	.2462	12,468	13,434	1361	2985	1.214	1.308	1574	1827	.459	1.085	48-206
19,750	.8773	10,524	11,534	666	1448	1.571	1.722	1074	1290	.291	.693	48-210
19,950	.8748	11,460	12,620	1114	2458	-----	---------	1177	1427	-----	---------	48-210
19,750	.8706	11,980	13,223	1349	2933	1.324	1.461	1308	1594	.496	1.191	48-210
19,750	.8690	12,468	13,843	1545	3359	1.306	1.450	1391	1715	.560	1.353	48-210
20,500	.8813	10,640	11,221	742	1644	1.709	1.833	1084	1247	.352	.837	48-210
19,800	.8657	11,580	12,369	1125	2421	1.324	1.414	1247	1423	.414	.952	48-210
20,200	.8757	12,136	12,981	1375	3025	1.255	1.342	1348	1542	.479	1.128	48-210
19,750	.8695	12,600	13,439	1565	3393	1.254	1.337	1427	1623	.545	1.261	48-210
30,250	.2442	11,616	13,037	1032	3525	1.162	1.304	1413	1780	.333	1.276	48-206
30,100	.2493	12,012	13,515	1072	3620	1.146	1.289	1520	1924	.341	1.296	48-206
30,100	.2493	12,500	14,081	1151	3887	1.182	1.332	1657	2103	.378	1.438	48-206
30,100	.7050	10,468	11,894	650	2195	1.237	1.406	1116	1441	.223	.857	48-206

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30,300	0.7148	11,504	13,120	899	3142	1.175	1.340	1282	1666	0.293	1.169	48-206
30,200	.7130	11,920	13,663	1024	3538	1.151	1.319	1340	1761	.328	1.297	48-206
30,250	.7092	12,480	14,342	1124	3839	1.167	1.341	1499	1970	.364	1.430	48-206
30,050	.8520	10,536	11,854	414	1404	2.027	2.280	1086	1375	.233	.890	48-206
30,200	.8560	11,506	12,978	845	2900	1.314	1.482	1254	1595	.308	1.193	48-206
30,200	.8560	11,970	13,484	953	3270	1.336	1.505	1350	1713	.354	1.367	48-206
30,200	.8560	12,420	13,991	1027	3524	1.384	1.559	1427	1811	.395	1.526	48-206
45,000	.2227	10,536	11,928	617	4322	1.328	1.503	1418	1817	.227	1.805	48-206
45,000	.2227	11,540	13,066	663	4649	1.338	1.516	1650	2120	.247	1.959	48-206
45,000	.2227	11,720	13,300	640	4484	1.388	1.575	1697	2185	.247	1.962	48-206
45,250	.6022	10,404	12,049	479	3364	1.770	2.050	1256	1684	.236	1.915	48-206
45,250	.6022	11,376	13,191	687	4824	1.322	1.533	1428	1920	.252	2.054	48-206
44,650	.5955	12,060	13,984	703	4812	1.388	1.609	1639	2204	.271	2.152	48-206
43,950	.5895	12,280	14,258	741	4960	1.325	1.538	1713	2309	.273	2.120	48-206
45,200	.8603	10,460	11,990	252	1778	2.349	2.693	1145	1504	.164	1.330	48-206
45,200	.8603	11,424	13,095	531	3747	1.273	1.459	1346	1767	.188	1.519	48-206
45,200	.8639	11,972	13,740	640	4516	1.217	1.397	1457	1919	.216	1.752	48-206
44,500	.8513	12,436	14,237	635	4367	1.313	1.504	1589	2083	.232	1.824	48-206
50,300	.2314	10,504	11,920	617	5460	.959	1.089	1506	1939	.164	1.651	48-210
49,800	.2146	11,258	12,775	565	4900	-----	---------	1720	2215	-----	---------	48-210
50,120	.7338	10,452	12,312	469	4128	1.275	1.502	1251	1736	.166	1.723	48-210
50,120	.7406	11,560	13,527	637	5607	1.162	1.360	1475	2020	.206	2.116	48-210
50,120	.7359	11,968	14,004	635	5590	1.240	1.451	1636	2240	.219	2.252	48-210
50,100	.8357	10,488	12,068	480	4210	1.278	1.470	1225	1622	.170	1.719	48-210
50,740	.8424	11,540	13,313	618	5588	1.213	1.399	1468	1954	.208	2.171	48-210
49,500	.8269	12,012	13,821	657	5601	1.231	1.416	1571	2080	.225	2.205	48-210
50,120	.8359	12,310	14,182	675	5942	1.245	1.434	1676	2225	.234	2.368	48-210

[a]Maximum rotor speed limited by capacity of exhauster system.

[redacted]

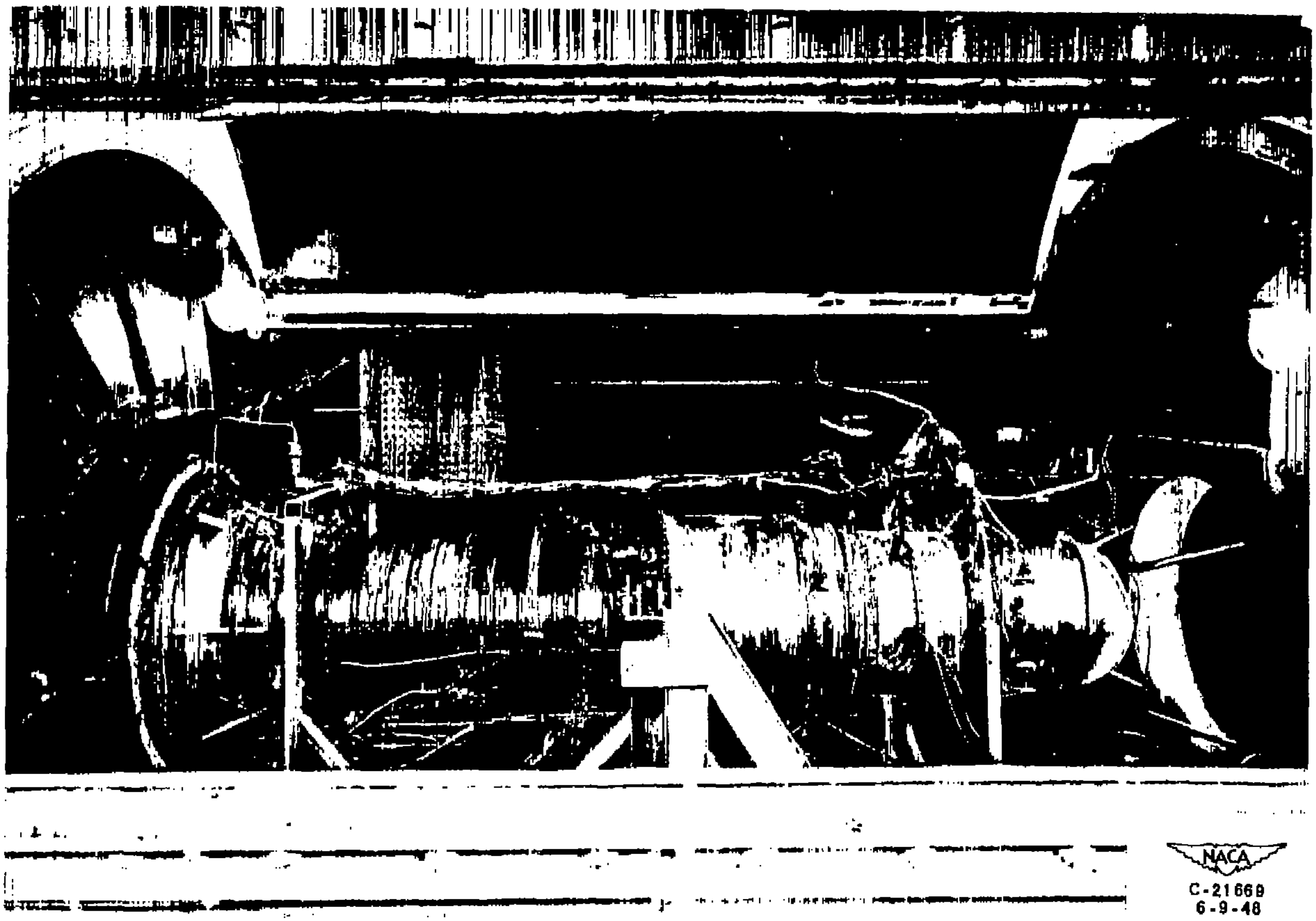


Figure 1. - Installation of 3000-pound-thrust turbojet engine with nonburning tail pipe and adjustable-area exhaust nozzle in 10-foot-altitude test chamber.

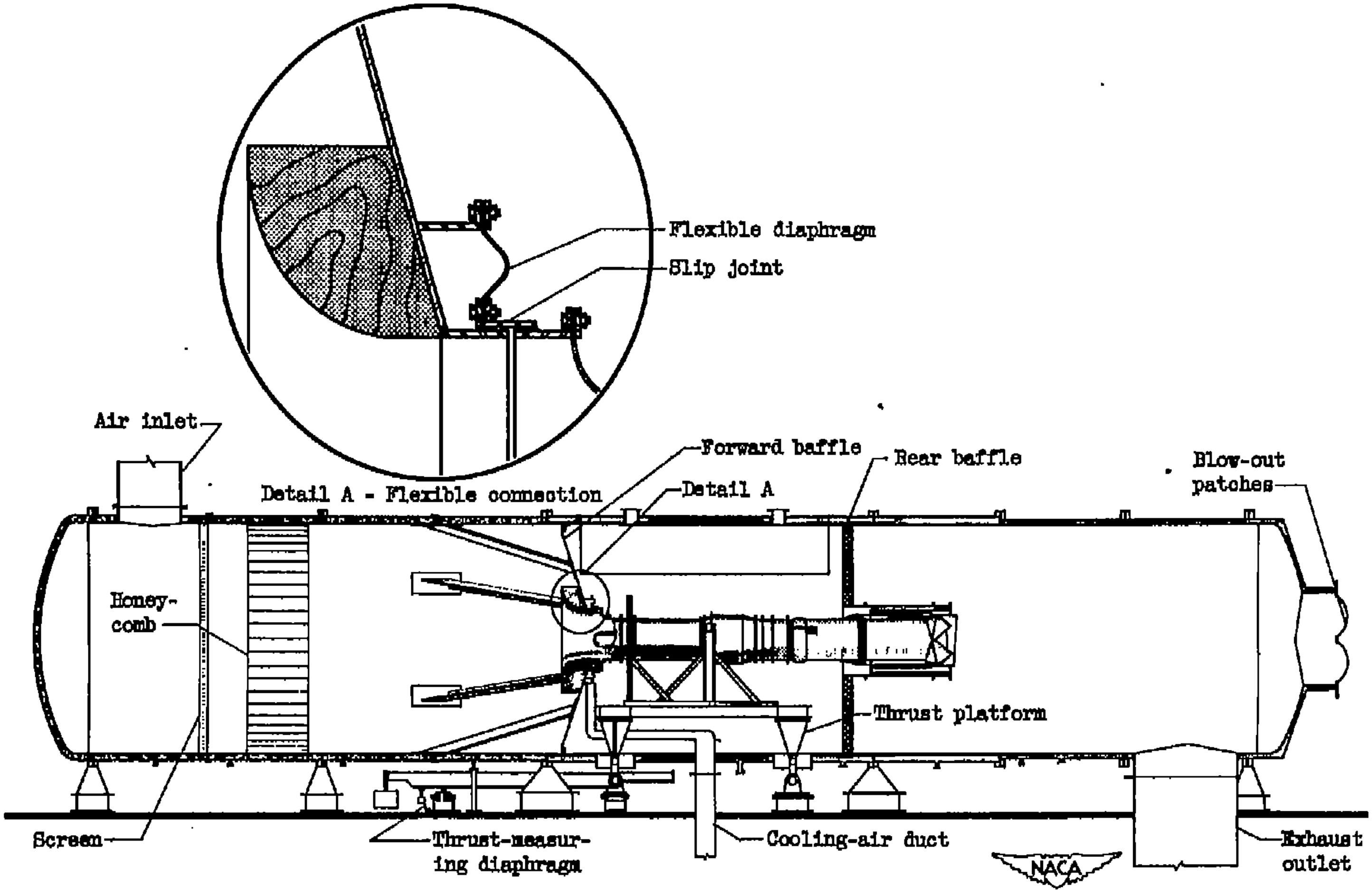
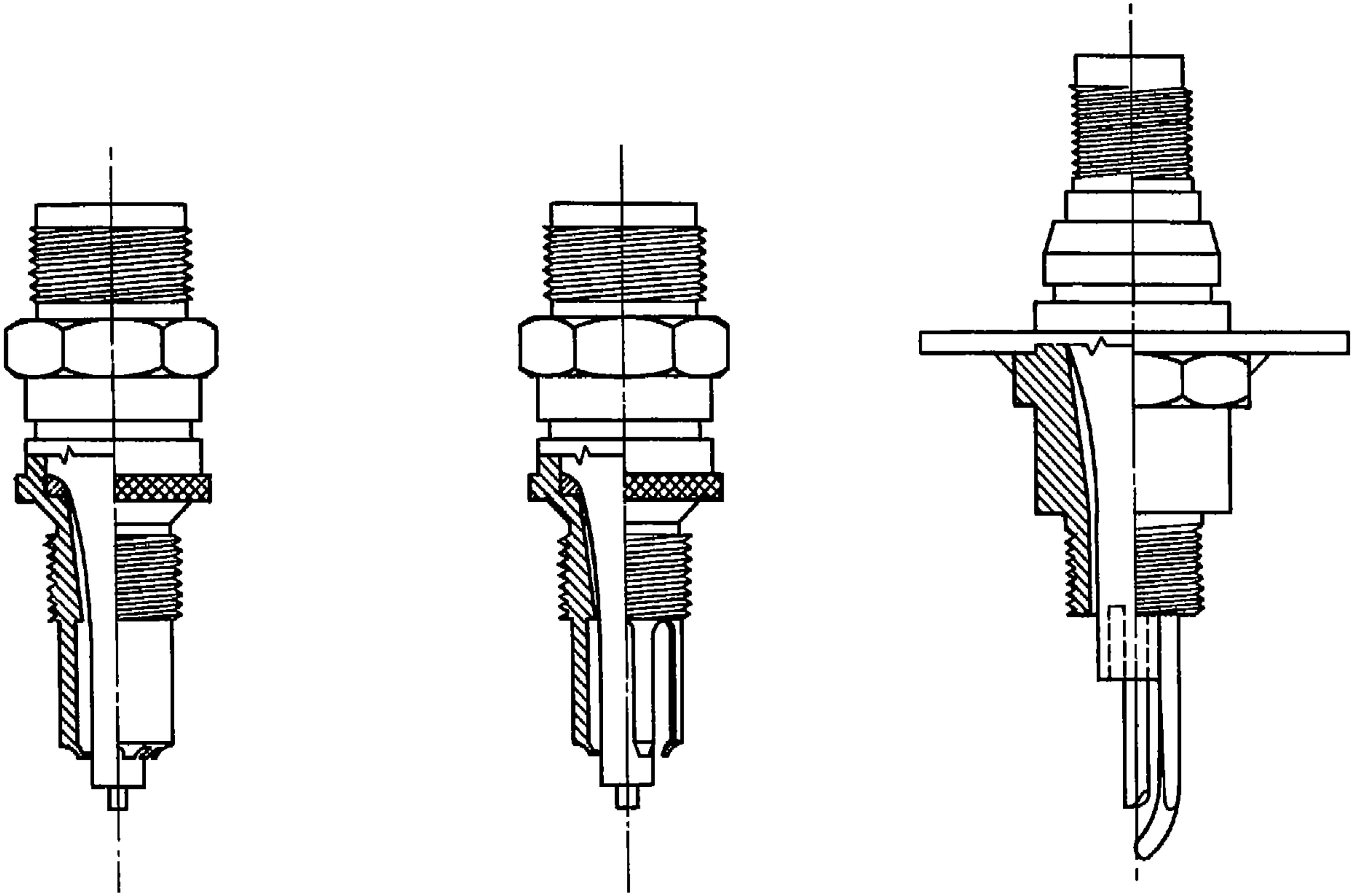


Figure 2. - General arrangement of turbojet-engine installation in altitude test chamber.

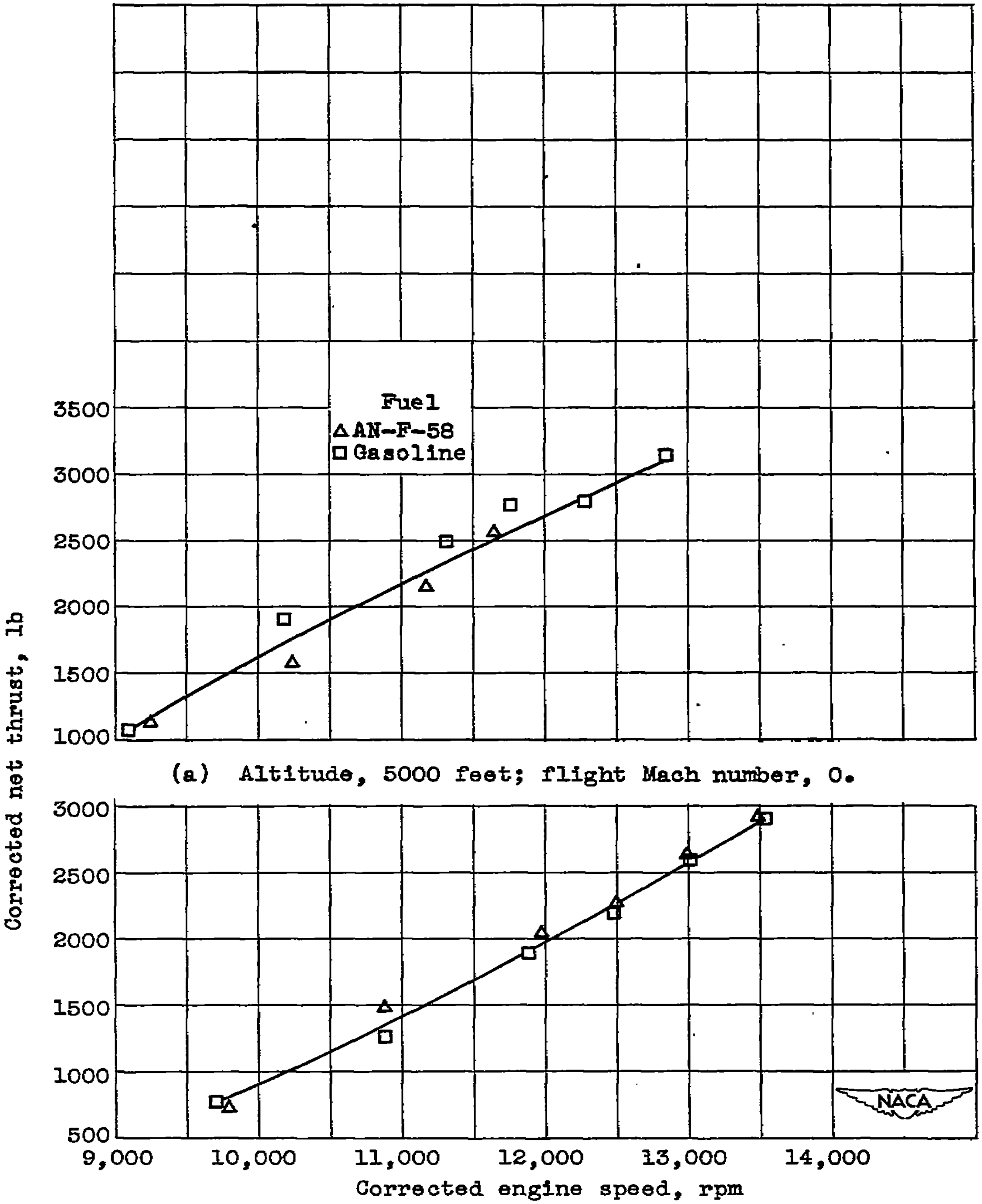


(a) Standard spark plug.

(b) Modified spark plug.

(c) Extended-electrode spark plug.

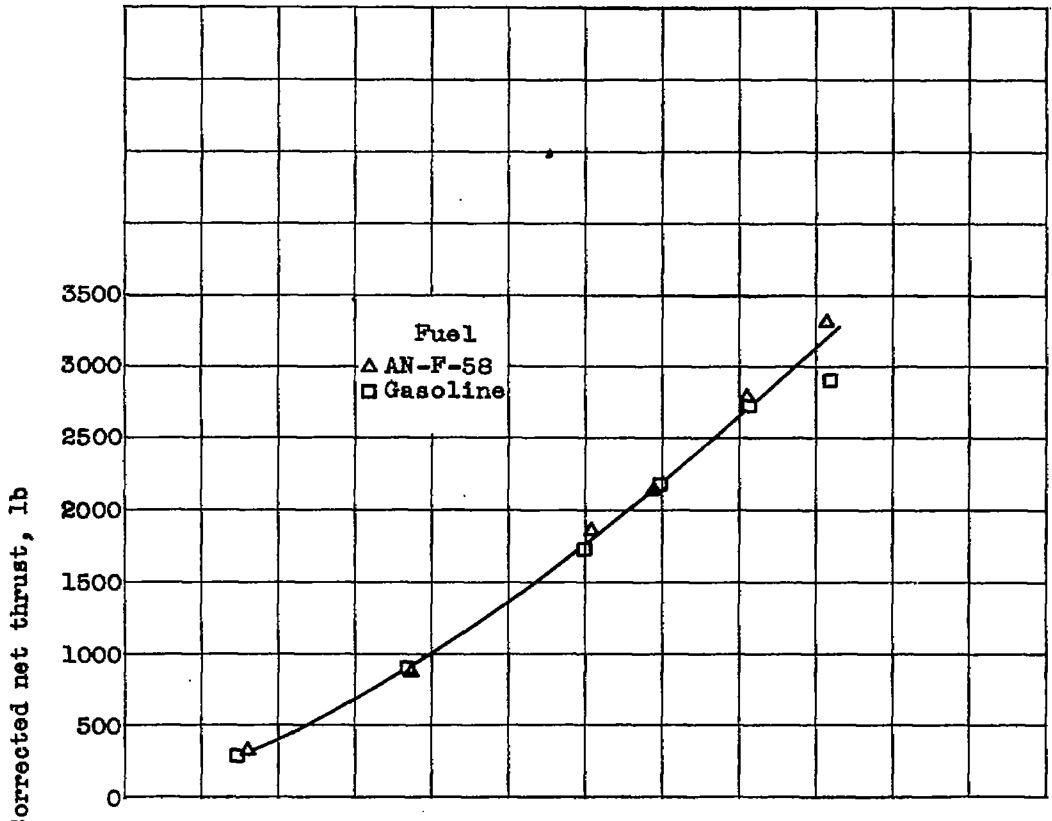
Figure 3. - Spark plugs used in starting.



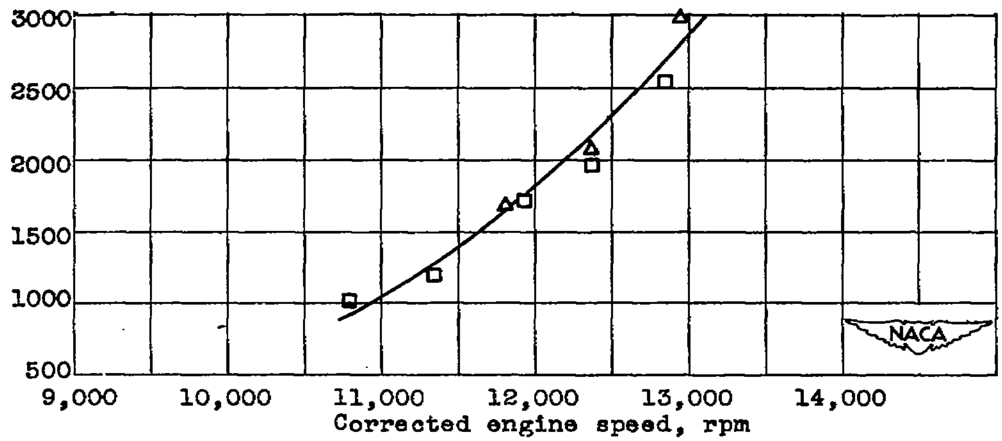
(a) Altitude, 5000 feet; flight Mach number, 0.

(b) Altitude, 20,000 feet; flight Mach number, 0.60.

Figure 4. - Comparison of corrected net thrust for AN-F-58 fuel and gasoline at various altitudes and flight Mach numbers.



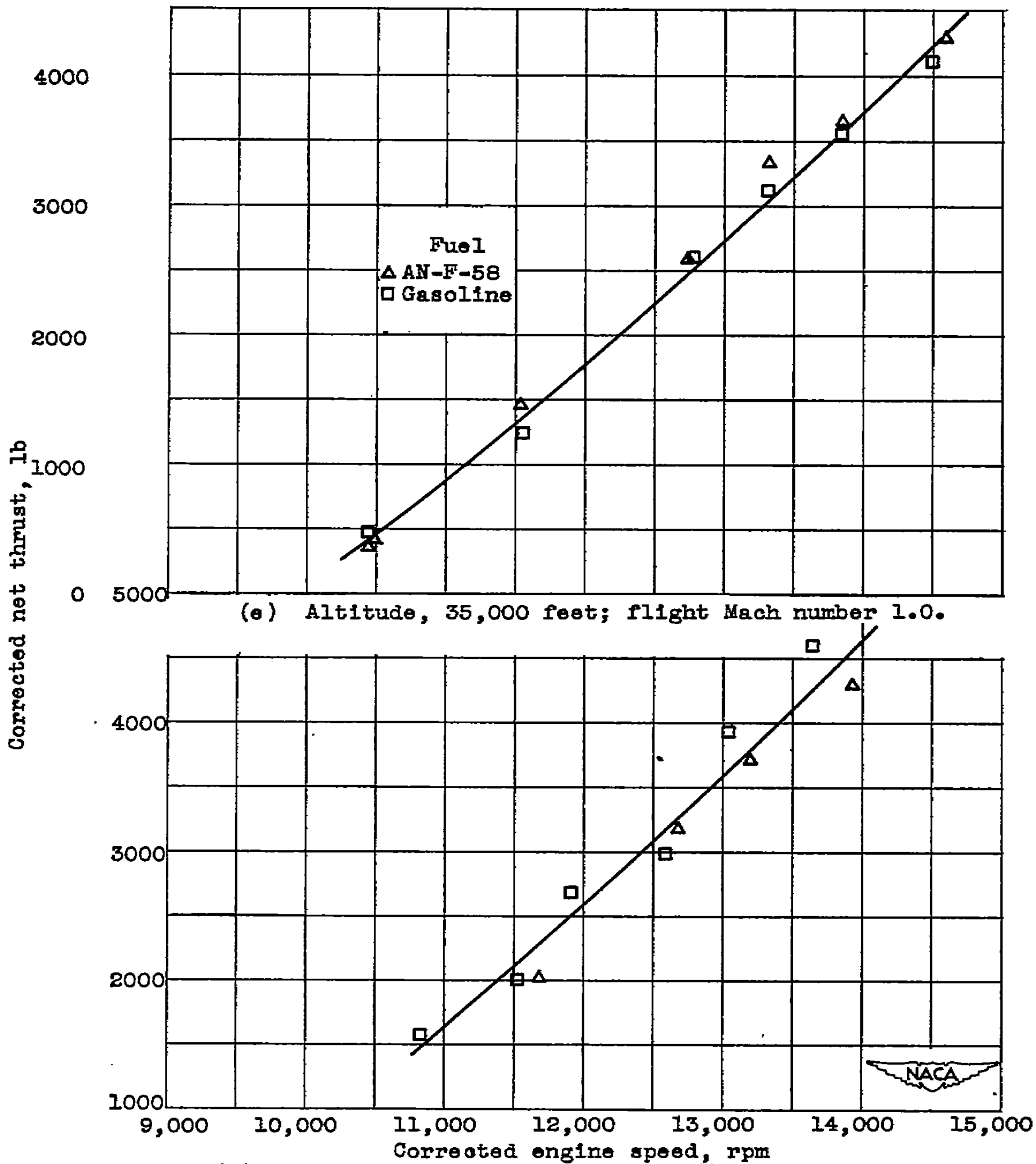
(c) Altitude, 20,000 feet; flight Mach number, 0.85.



(d) Altitude, 20,000 feet; flight Mach number, 1.00.

Figure 4. - Continued. Comparison of corrected net thrust for AN-F-58 fuel and gasoline at various altitudes and flight Mach numbers.

1070

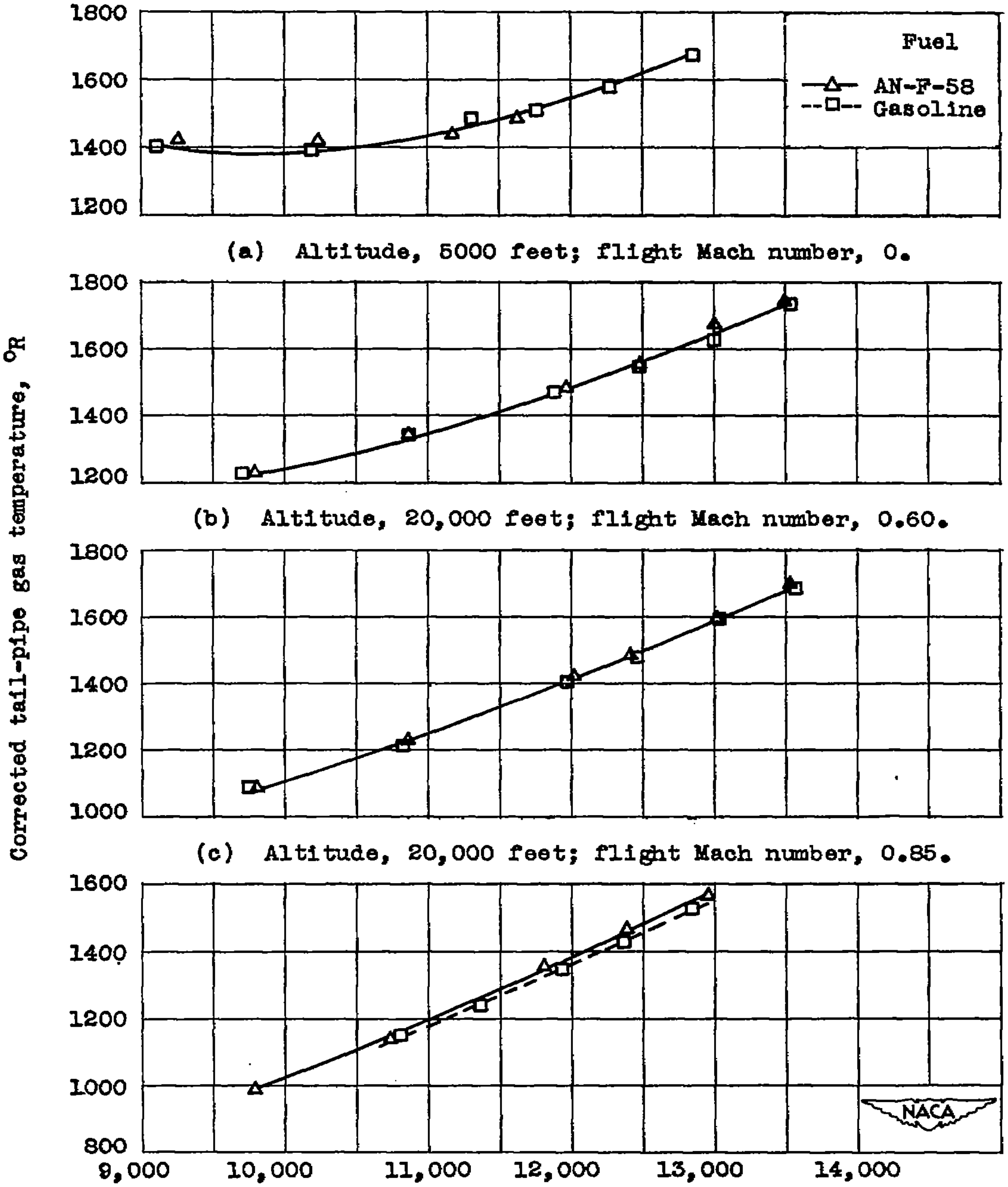


(e) Altitude, 35,000 feet; flight Mach number 1.0.

(f) Altitude, 50,000 feet; flight Mach number, 0.85.

Figure 4. - Concluded. Comparison of corrected net thrust for AN-F-58 fuel and gasoline at various altitudes and flight Mach numbers.

1070



(a) Altitude, 5000 feet; flight Mach number, 0.

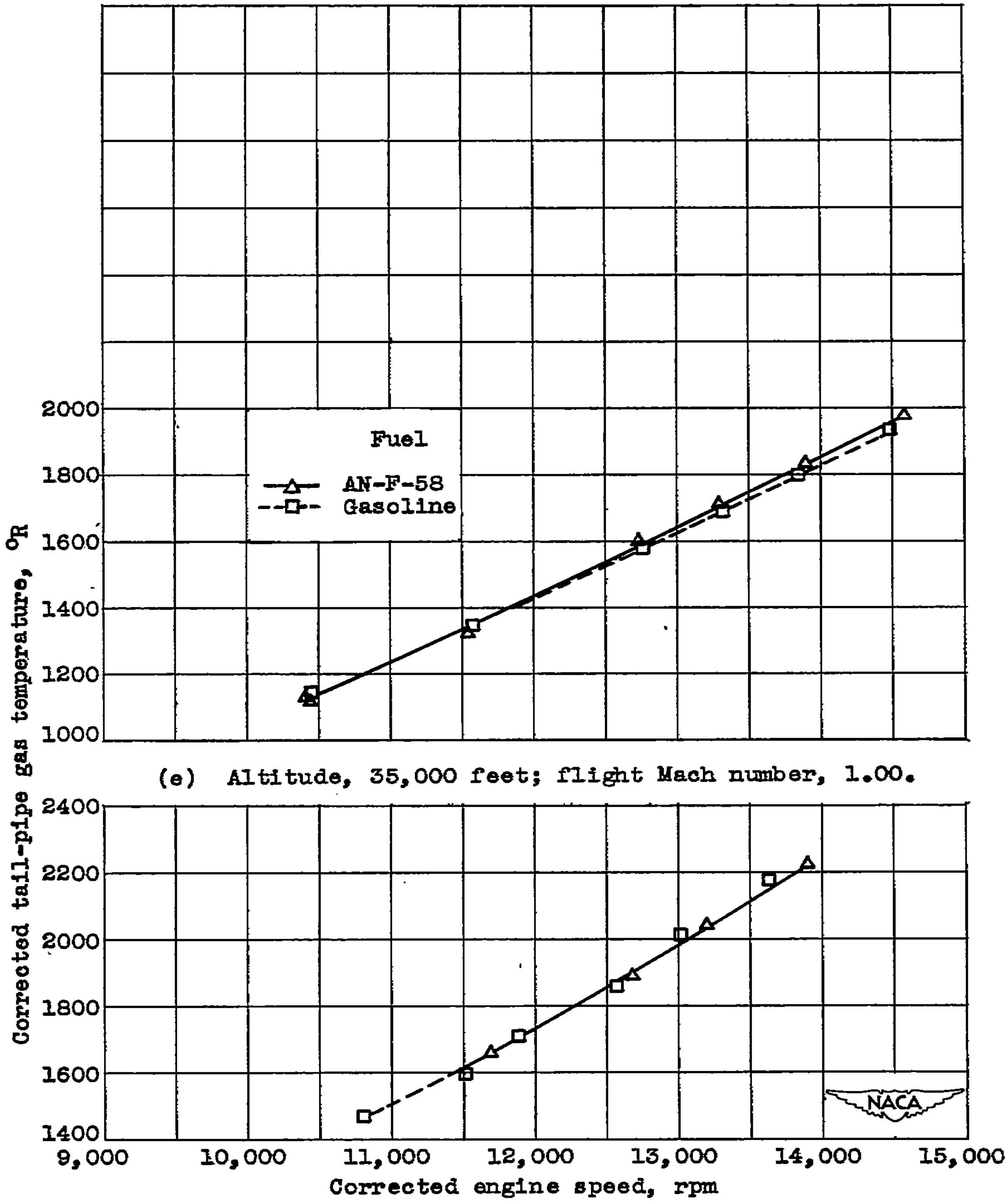
(b) Altitude, 20,000 feet; flight Mach number, 0.60.

(c) Altitude, 20,000 feet; flight Mach number, 0.85.

(d) Altitude, 20,000 feet; flight Mach number, 1.00.

Figure 5. - Comparison of corrected tail-pipe gas temperature for AN-F-58 fuel and gasoline at various altitudes and flight Mach numbers.

1070



(e) Altitude, 35,000 feet; flight Mach number, 1.00.

(f) Altitude, 50,000 feet; flight Mach number, 0.85.

Figure 5. - Concluded. Comparison of corrected tail-pipe gas temperature for AN-F-58 fuel and gasoline at various altitudes and flight Mach numbers.

1070

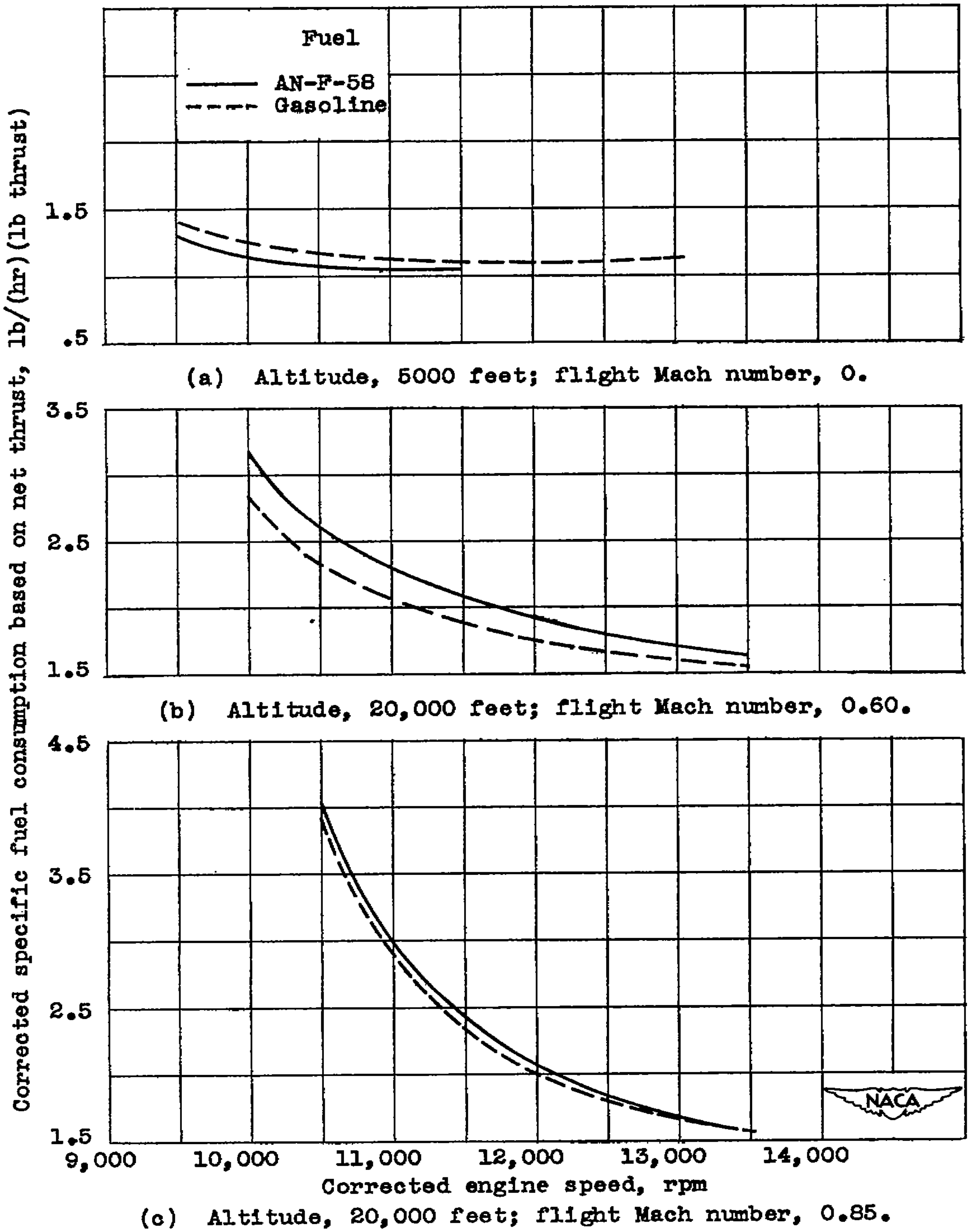
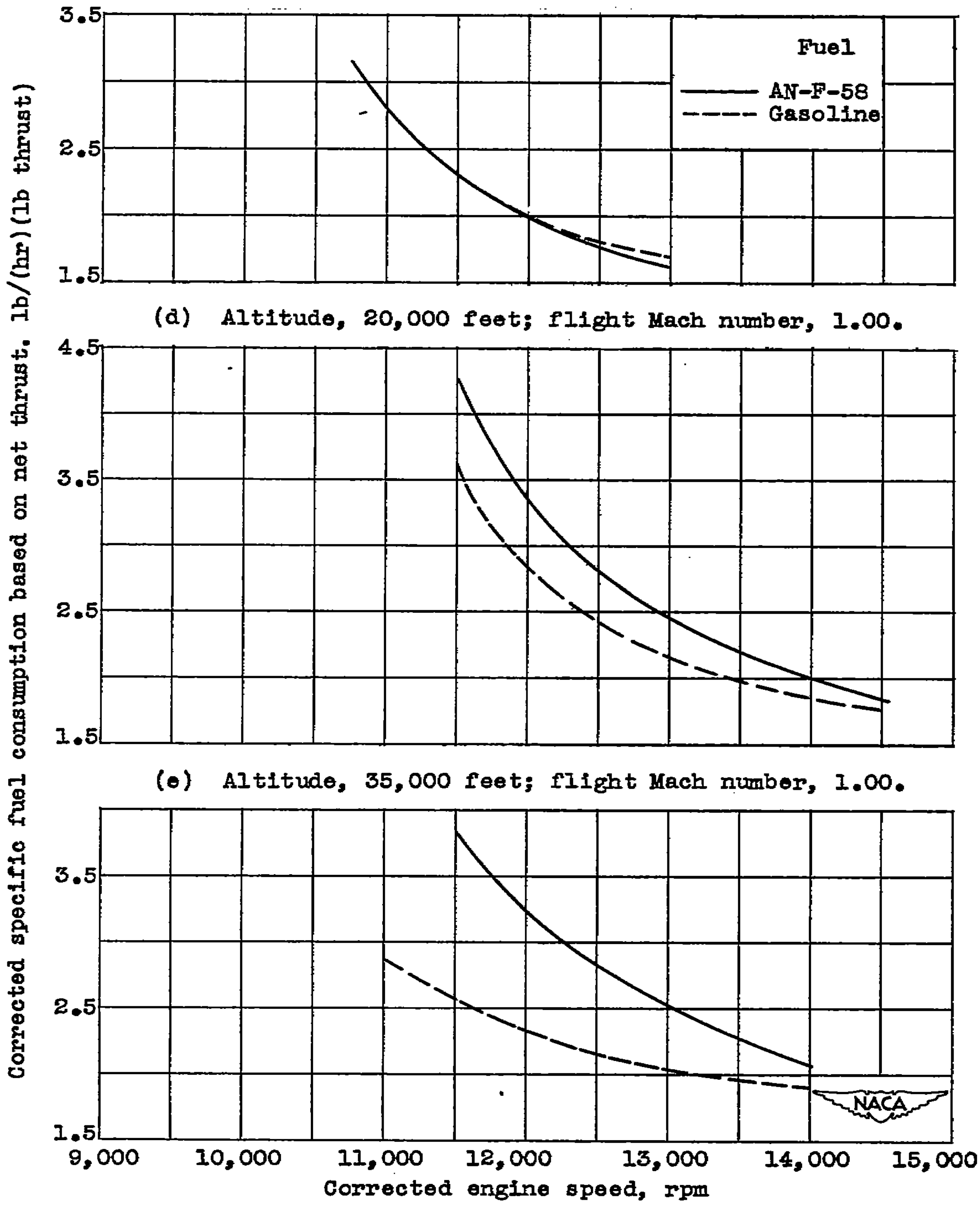


Figure 6. - Comparison of corrected specific fuel consumption based on net thrust for AN-F-58 fuel and gasoline at various altitudes and flight Mach numbers.

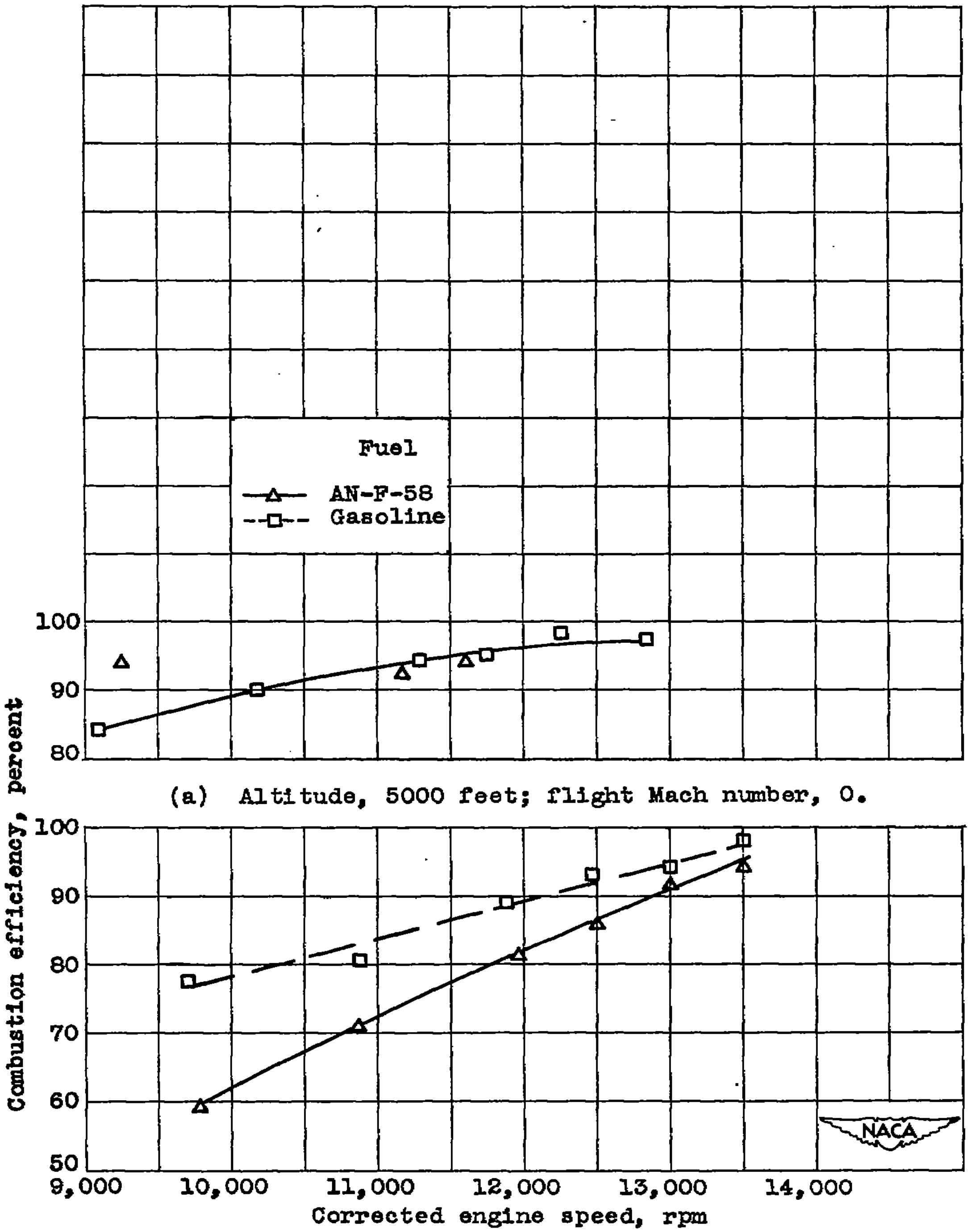


(d) Altitude, 20,000 feet; flight Mach number, 1.00.

(e) Altitude, 35,000 feet; flight Mach number, 1.00.

(f) Altitude, 50,000 feet; flight Mach number, 0.85.

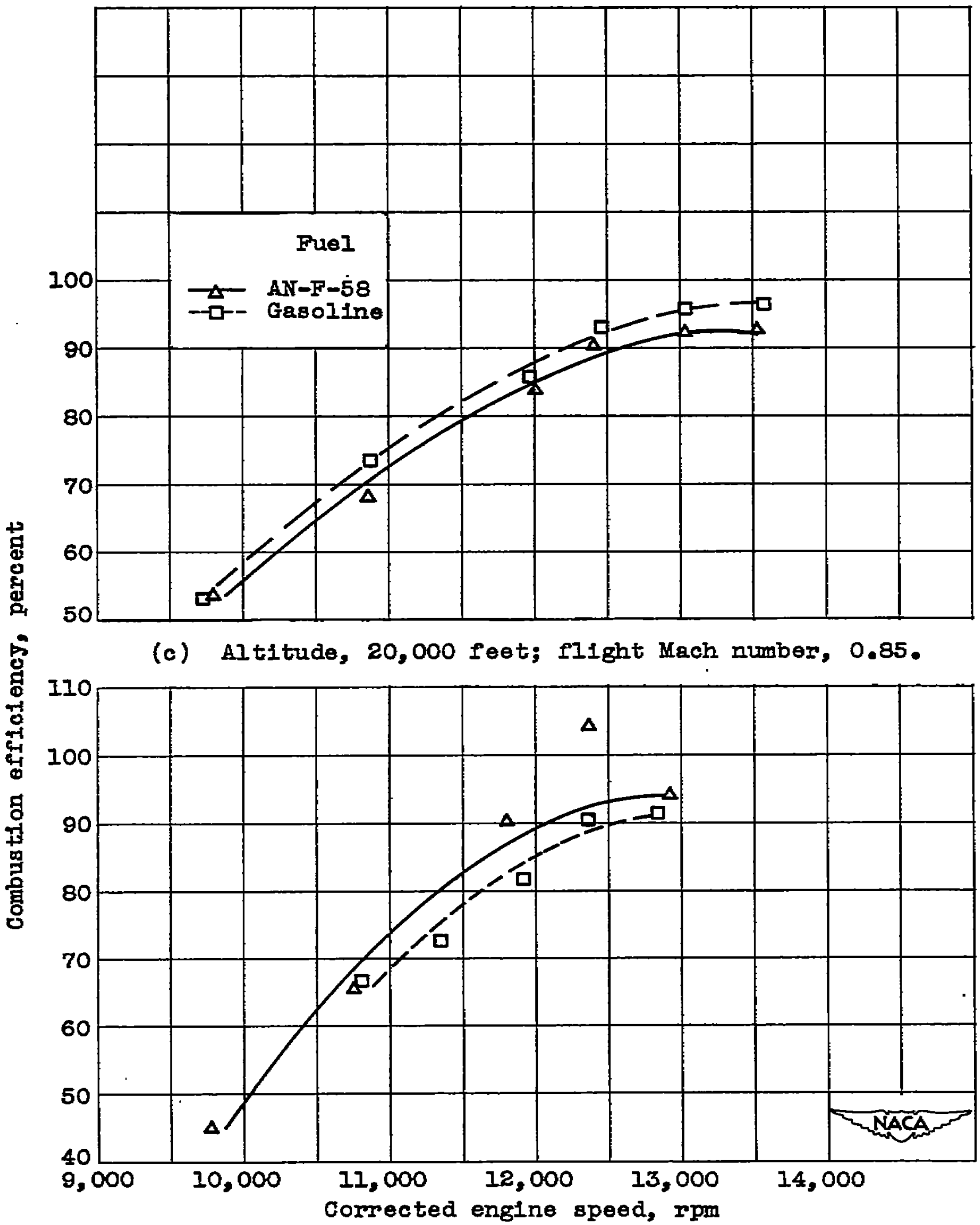
Figure 6. - Concluded. Comparison of corrected specific fuel consumption based on net thrust for AN-F-58 fuel and gasoline at various altitudes and flight Mach numbers.



(a) Altitude, 5000 feet; flight Mach number, 0.

(b) Altitude, 20,000 feet; flight Mach number, 0.60.

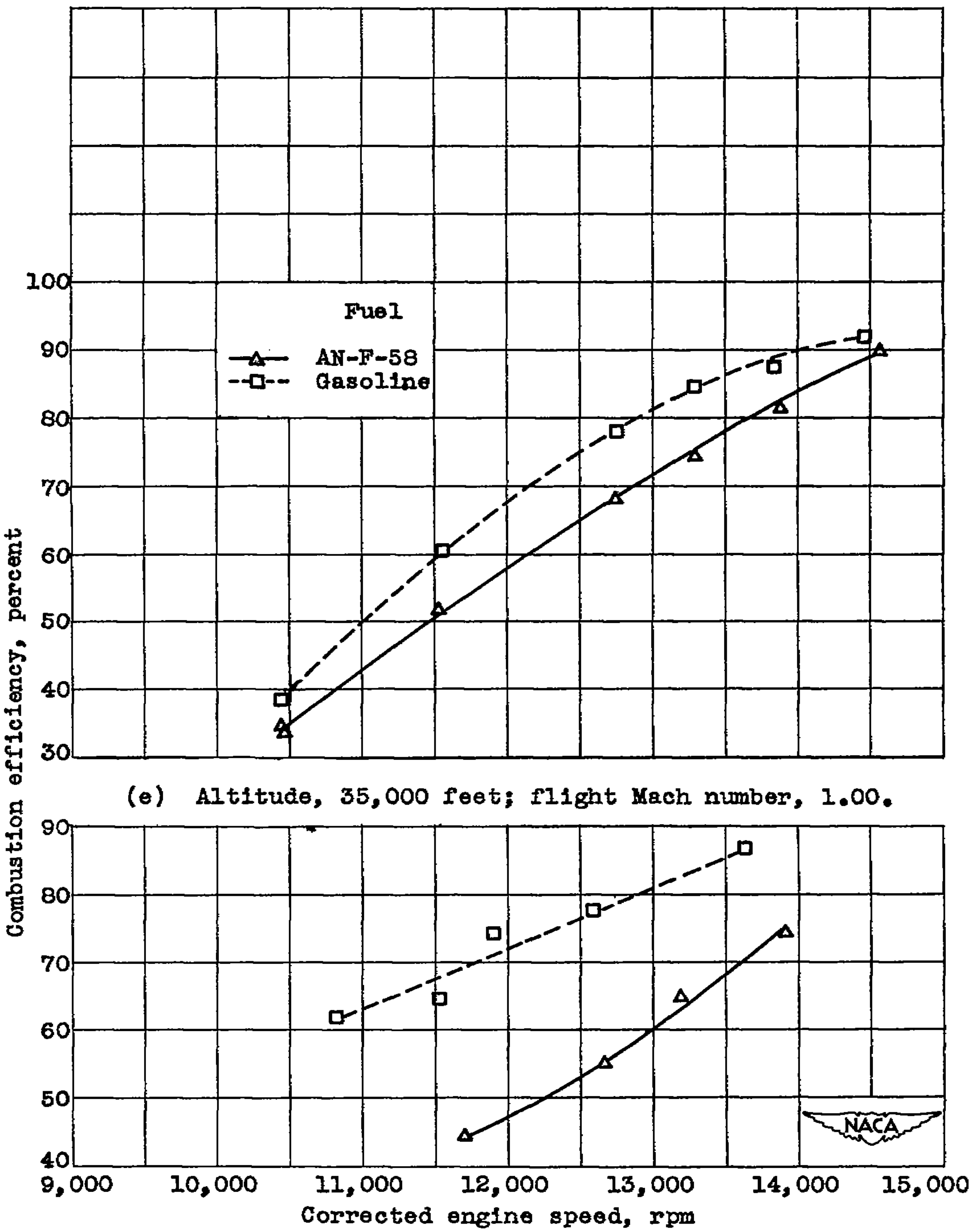
Figure 7. - Comparison of combustion efficiency for AN-F-58 fuel and gasoline at various altitudes and flight Mach numbers.



(c) Altitude, 20,000 feet; flight Mach number, 0.85.

(d) Altitude, 20,000 feet; flight Mach number, 1.00.

Figure 7. - Continued. Comparison of combustion efficiency for AN-F-58 fuel and gasoline at various altitudes and flight Mach numbers.



(e) Altitude, 35,000 feet; flight Mach number, 1.00.

(f) Altitude, 50,000 feet; flight Mach number, 0.85.

Figure 7. - Concluded. Comparison of combustion efficiency for AN-F-58 fuel and gasoline at various altitudes and flight Mach numbers.

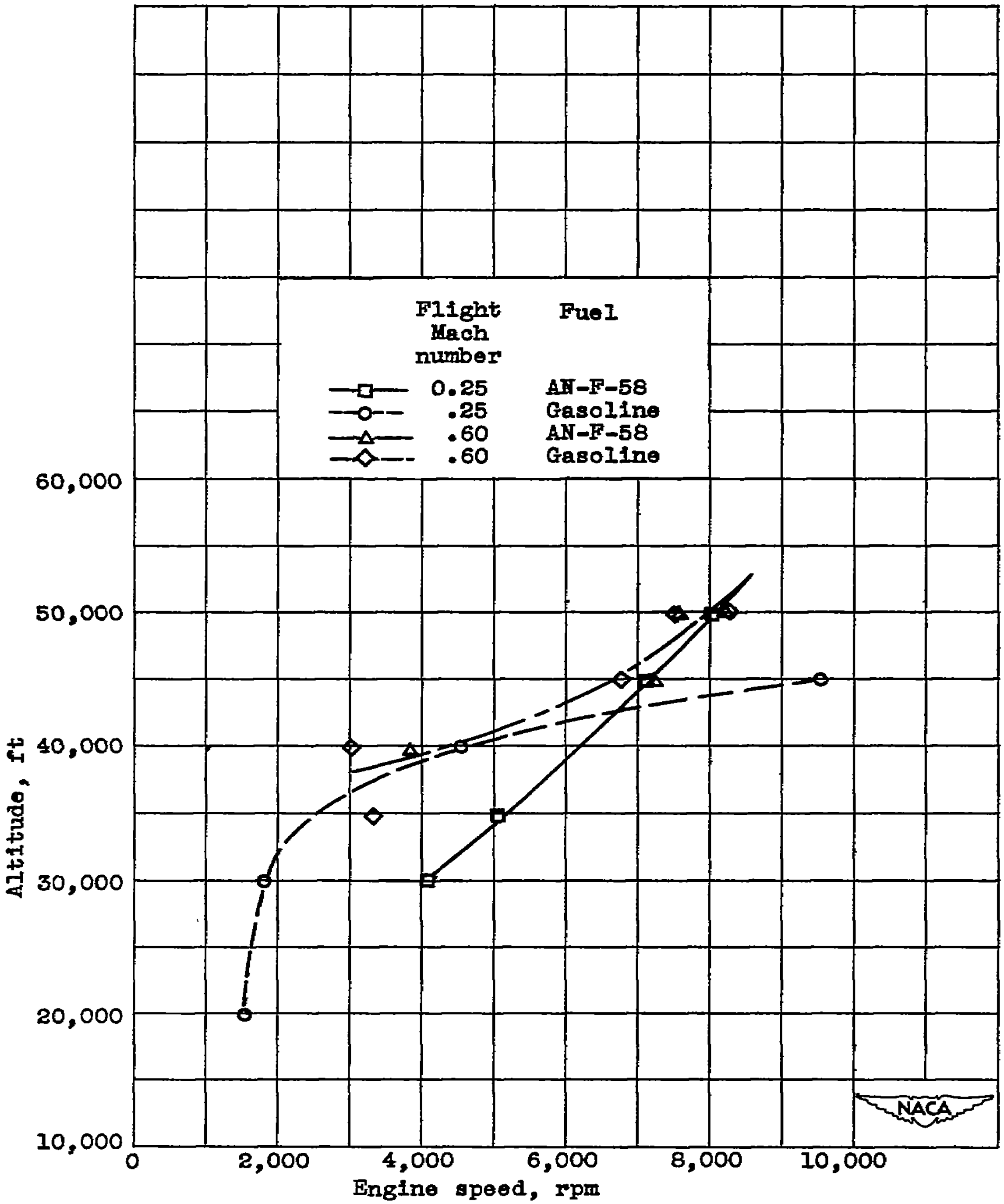
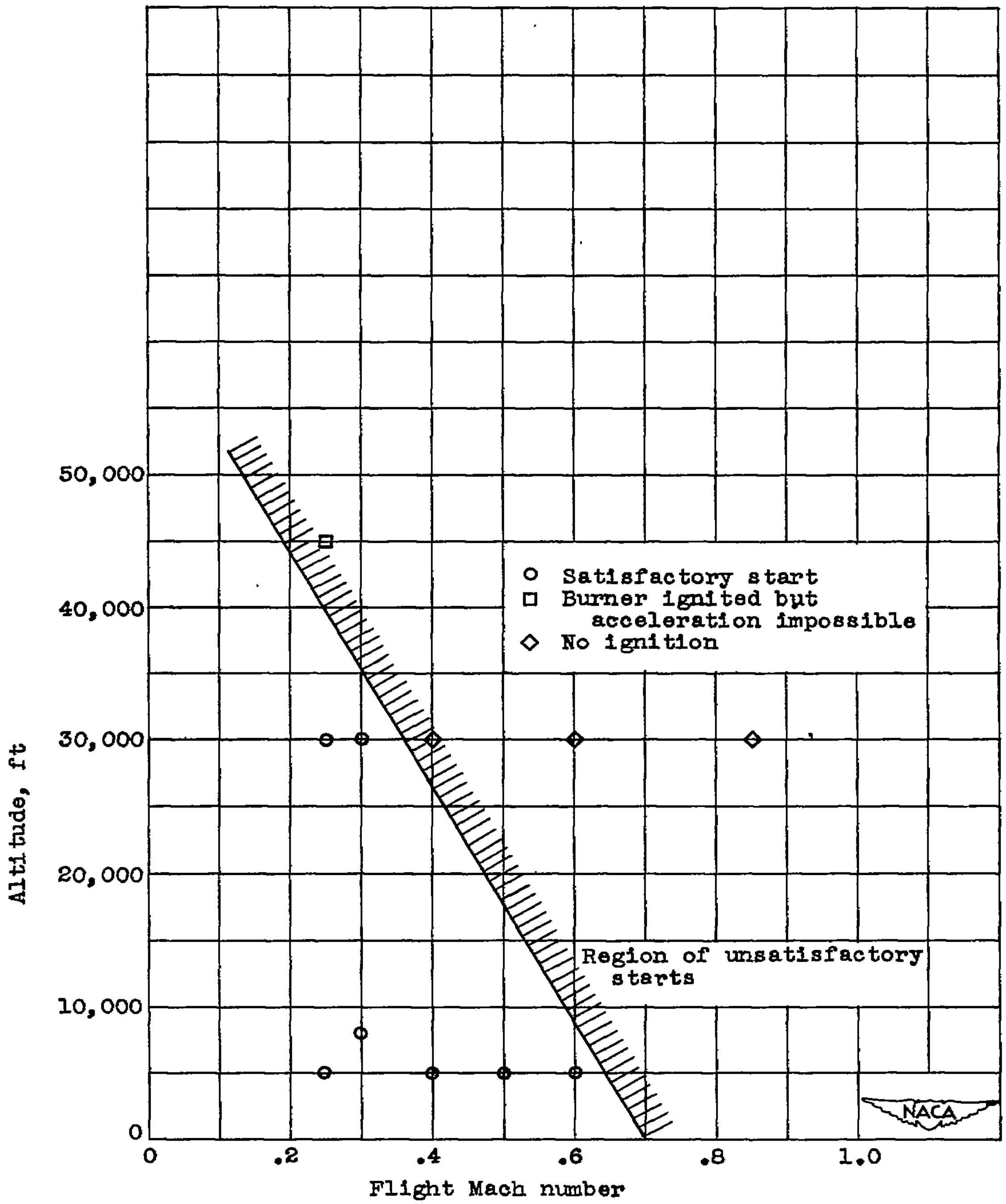


Figure 8. - Low engine-speed blow-out limits for AN-F-58 fuel and gasoline.

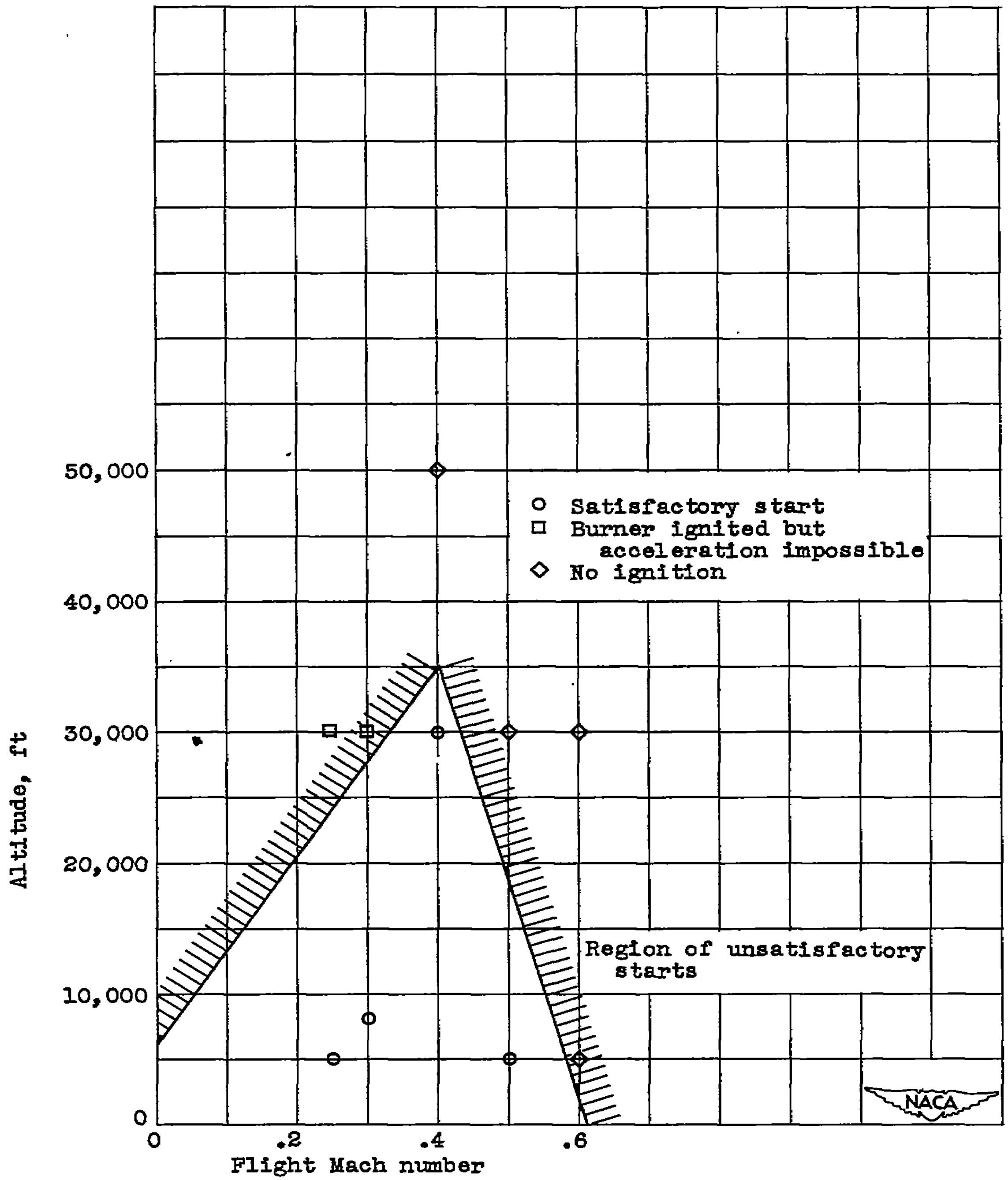
1070



(a) Fuel, AN-F-58; standard spark plug; plug cleaned for every run.

Figure 9. - Windmilling-starting characteristics.

1070



(b) Fuel, AN-F-58; extended-electrode spark plug; plug not cleaned between runs.

Figure 9. - Continued. Windmilling-starting characteristics.

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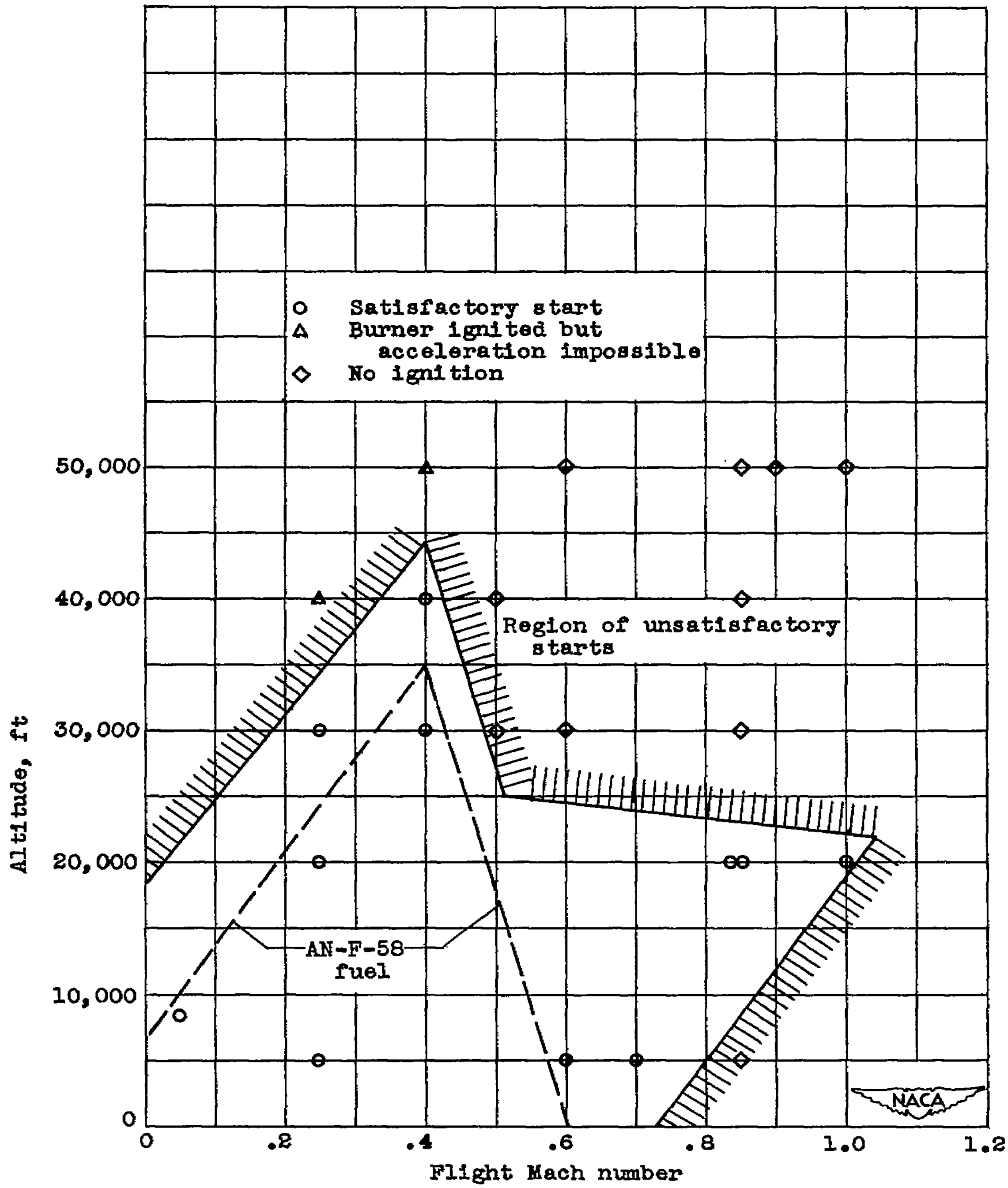

(c) Fuel, gasoline; standard spark plug; dashed line from figure 9(b).

Figure 9. - Concluded. Windmilling-starting characteristics.

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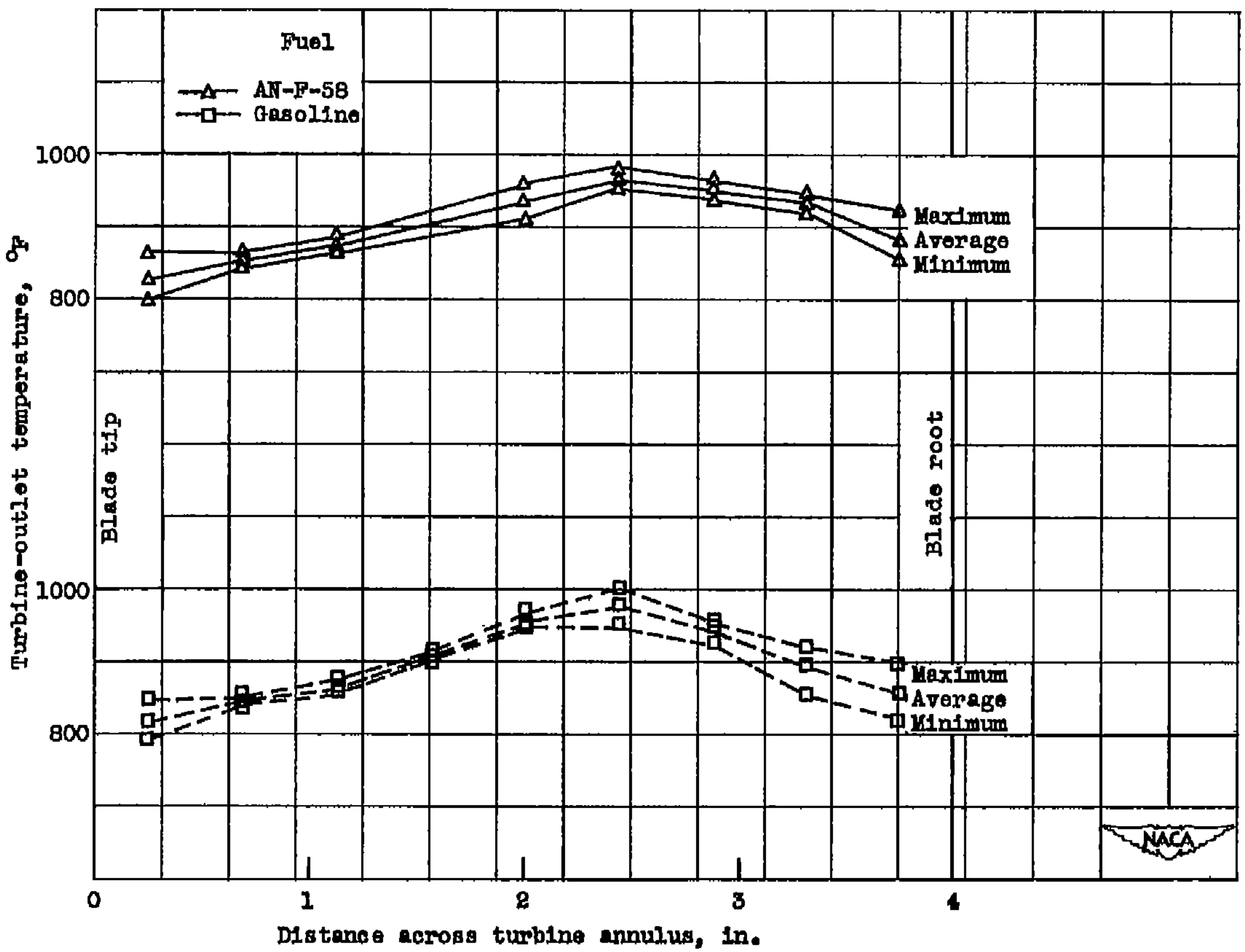
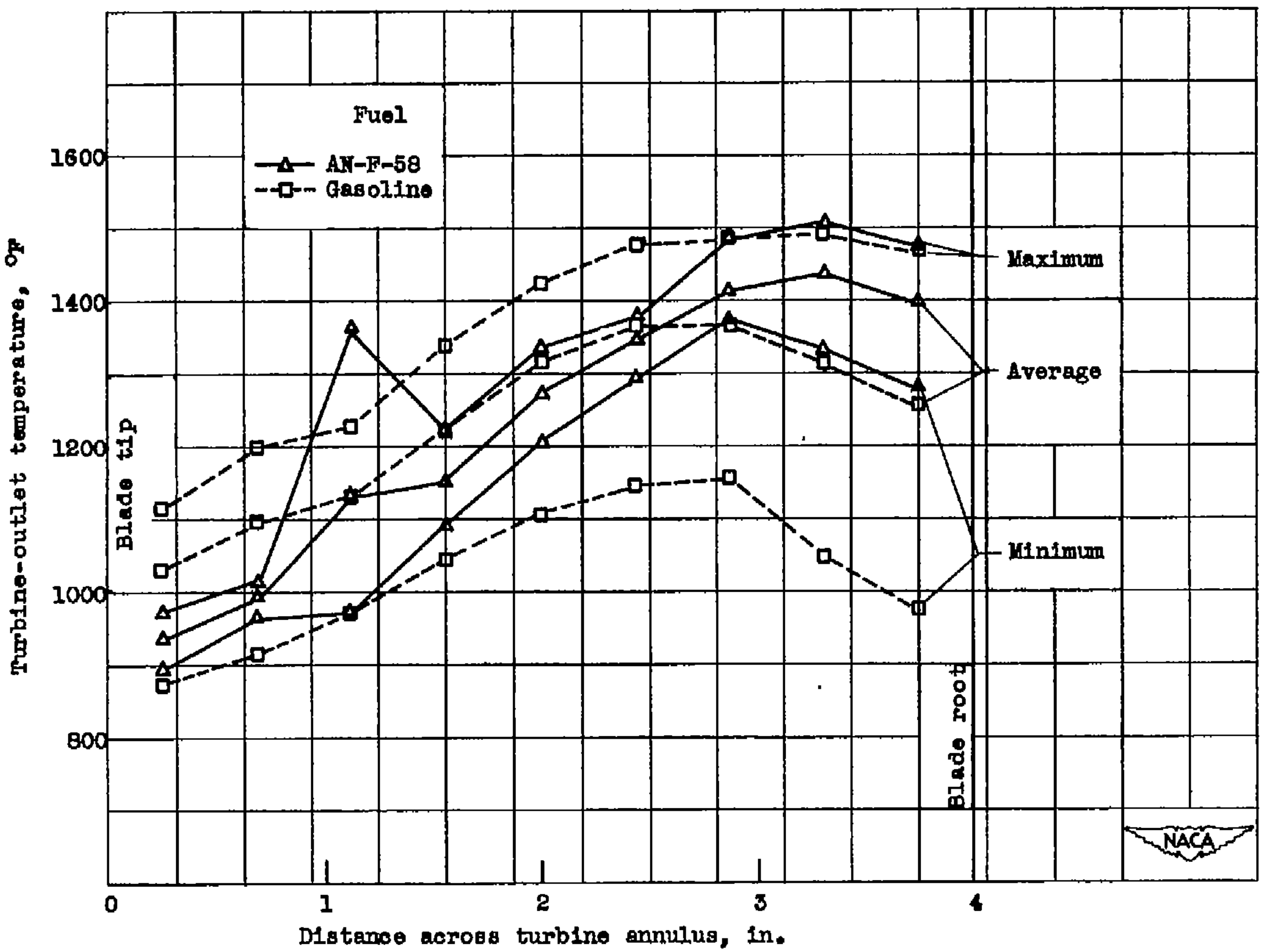


(a) Altitude, 20,000 feet; engine speed, approximately 12,025 rpm.

Figure 10. - Radial temperature distribution at turbine outlet for AN-F-58 fuel and gasoline. Flight Mach number, 0.85.

[redacted]

[redacted]



(b) Altitude, 50,000 feet; engine speed, approximately 12,050 rpm.

Figure 10. - Concluded. Radial temperature distribution at turbine outlet for AN-F-58 fuel and gasoline. Flight Mach number, 0.85.

[redacted]

[redacted]

Figure 11. - Combustor basket looking upstream from turbine showing carbon deposits on two rings.